

Development of a Low-Magnetic Power Source for a Diver Propulsion Vehicle

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LONG-TERM GOALS

The long-term goal of this research is to develop a low-magnetic power source for use in diver propulsion. Current Diver Propulsion Vehicles (DPV) use batteries to power an electric motor. Both the batteries and the motor systems are highly magnetic making them unsuitable for use in an environment where magnetic influence ordnance may be deployed. In order to operate in these theaters, an air independent power source must be developed using low-magnetic materials and methods capable of operating for long durations in harsh environments.

OBJECTIVES

This effort was directed at assessment of technologies to meet the nonmagnetic and other performance goals, building a representative prototype of the most appropriate approach to verify performance/safety compliance, and bench testing of the power source for preliminary evaluation.

APPROACH

This research program has had three phases. In Phase I, a technology survey and evaluation was conducted to formulate an unbiased and regimented method for selection of a power technology that lent itself best to all performance requirements including non-magnetic adaptation.

In Phase II, a prototype power source was designed and constructed, along with the necessary modeling and analysis, to assess the lowest level of program risk, engine performance, and a high level of safety.

In Phase III, a bench top evaluation was conducted to assess system and sub-system performance and to develop recommendations for a transitionable, follow-on power source.

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 1998		2. REPORT TYPE		3. DATES COVERED 00-00-1998 to 00-00-1998	
4. TITLE AND SUBTITLE Development of a Low-Magnetic Power Source for a Diver Propulsion Vehicle				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Surface Warfare Center, Coastal Systems Station Code A51,6703 W. Highway 98, Panama City, FL, 32407				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM002252.					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 5	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

WORK COMPLETED

In fiscal 1997 (program initiation), a technology assessment was conducted to determine the most promising approach to be carried on to Phase II. This assessment considered all potential power sources including electric motor, internal and external combustion engines, and nuclear generators. Candidate approaches were systematically rated using weighed criteria that included performance concerns, delectability, and safety. Approaches were also ranked in accordance with estimated development risk, taking into consideration maturity, commercial prevalence, and ultimate cost.

As a result of the Phase I assessment, it was decided that a Stirling cycle engine showed the most promise for meeting both the performance requirements and addressing non-magnetic concerns. For Phase II, a commercial and university search was conducted to locate an experienced institution to analyze, design and build a Stirling power source. The Mechanical Engineering Department at the University of Calgary had extensive experience and on-site expertise in the area of Stirling engines and was selected to conduct the engine development/testing for the program. In the final phase of this research effort the delivered engine was run through a series of bench top, laboratory tests to assess performance and areas of possible engine improvement.

RESULTS

The design tradeoff studies conducted by Calgary as part of their Stirling engine development led to a 450-watt engine that utilized a double acting piston and separate displacer within an elevated pressure housing (@200 psi). The combustion chamber is separate from the engine compartment and is fueled by kerosene and compressed oxygen. Waste heat is exchanged with the environment by use of an open circuit water system. The first engine prototype was delivered to the Navy (Figure 1) in April of 1998 for sub-system bench top testing.

Prior to delivery, the University of Calgary had conducted “back-motoring” tests of the engine to determine mechanical / sealing integrity and thermodynamic capability through refrigeration measurements. During these mechanical trials, wear associated problems with some plastic components necessitated remanufacture of the parts with low-signature metals. All suspect components were replaced prior to delivery to the Navy. Temperature measurements taken at the combustor head coils during back-motoring indicated thermodynamic performance consistent with preliminary estimates.

Navy testing consisted of separate mechanical tests (back-motored), combustor function tests, magnetic signature screening, and a final external heat, application test. The combustor assembly had not been tested assembled and up to working pressure (180 psi) when delivered to the Navy. It was determined that combustor testing at the Navy should proceed from an unassembled posture. With the supplied control system in place, and the combustor head separated from the engine, reliability testing of the combustor flame began. To obtain combustion, it is necessary to atomize the kerosene and mix it with oxygen. This testing was undertaken in two phases. The first phase was burning of the atomized kerosene in room air with normal oxygen concentrations. The second phase was to combust the atomized kerosene while applying pure oxygen.

Initial testing of flow from the kerosene injector mounted in the combustor cone shows that atomization of kerosene was brief. Kerosene flow from the 0.0012" diameter orifice of the injector stops in less than one minute. The kerosene flow and atomization tests were conducted with four different injectors. The results were similar with each injector atomizing the kerosene for a brief period (< 1 min.) before clogging and stopping the kerosene flow. During these short intervals when the kerosene was flowing and atomized, the oxygen was added in the combustor cone and ignited. The flame burned until each orifice clogged. Typical burn times were approximately 30 seconds.

Figure 2 shows particle blockage of a laser bored Ruby injector with a 0.0012" orifice used in the flow/atomization testing as seen under an electron microscope. Analysis of the clogging material revealed that it was aluminum oxide, the source has not been identified. Filters were relocated in the control system plumbing to eliminate the presence of valves between the filters and the injector. A two-stage filter system of a 7-micron filter followed by a 0.5-micron filter was used. Clogging of the injectors continued.

Tests of kerosene injectors with larger diameter orifices were conducted. The injectors with 0.0016" orifice diameters were tested with 3 ml/min flow rates at 175 psi supply pressures and 1.5 ml/min flow rates at 60 psi supply pressures. The nozzles with 0.0020" diameter orifices were tested with 3 ml/min flow rates at 80 psig supply pressures and 1.5 ml/min flow rates at 30 psig supply pressures. After several tests, it was determined that reliability was improved. Some clogging was still occurring due to pooling of the fuel at the nozzle exit. Additional testing will be necessary to determine the orifice size and nozzle modifications that maximize combustion reliability.

For mechanical evaluation the engine was mounted to a dynamometer and back-motored repeatedly. During these tests there were numerous mechanical failures that required repair or modification to the engine. Also measured during the mechanical evaluations were temperatures at the heater tubes at various working gas pressures. Magnetic Screening of all subassemblies and components was completed to assess compliance with Mil-M-19595C. The major testing results, modifications, and recommendations are summarized in Table 1.

The research has demonstrated that a small, low- signature DPV power source is attainable through the use of Stirling cycle engines.

IMPACT/APPLICATIONS

Successful transition of this development will allow for the development of a diver propulsion system that permits safer and more effective missions in currently prohibitive theaters of operation. A high capacity, hydrocarbon fueled DPV allows for diver insertions from greater standoff distances decreasing diver detection risk and permitting alternate insertion platforms (ASDS, submarine).

The non-magnetic capability of this system will lead to propulsion vehicle that can operate safely in waters where magnetic influence mines may be present. This would fill a current gap for both the Explosive Ordnance Disposal (EOD) components and also for the Special Warfare forces operating in a littoral environment.

TRANSITIONS

Research conducted under this project in alternate non-magnetic power sources will lead ultimately to the development of a multi-function, long range, LPI / LPD diver capability. Alternate use of this propulsion technology could be in Remotely Operated Vehicles (ROV) for very shallow water (VSW) mine countermeasures (MCM).

This work is being transitioned for further development under the Office of Naval Research's (ONR) Surf Zone (SZ)/VSW MCM) core program. It is expected to eventually transition to the VSW MCM Detachment in Coronado, CA.

RELATED PROJECTS

PEO Mine Warfare is currently investigating commercially available DPVs for double diver applications. Close coordination of their effort and the ONR core effort will allow for product improvement integration of the Stirling power source into the next generation VSW-MCM DPV.

Subsystem Test	Result	Repair for Test	Recommendation
Combustor Subsystem Test	Orifice clogging	Larger Orifice	Larger orifice with pulsed flow, Redesign of fuel supply path
Combustor Subsystem Test	Heater tube flame impingement	Unmodified	Use high temperature, casted, heat tiling
Mechanical Integrity Test	Cylinder pressure / thermodynamic imbalance	Modified cylinder seal	Tighter cylinder tolerances, Cylinder material change to Titanium, Improved cylinder seal design
Mechanical Integrity Test	Failure of high pressure gas transfer tube	Modified tube and bulkhead fitting	Permanent, fixed transfer tube configuration
Mechanical Integrity Test	Displacer phase angle slippage	Modified flywheel hub locking ring, Knurled shaft	Key or knurl shaft, Change flywheel hub locking ring material.
Mechanical Integrity Test	Excessive wear of various power and control components	Unmodified	Change plastic and brass components to stronger / high wear metal materials
Magnetic Screening Test	All components passed with the exception of combustor	Unmodified	Change material from stainless steel to low-magnetic alloy.
External Heat Application Test	No appreciable power output when heat applied	Unmodified	Redesign combustor deficiencies and apply sufficient, uniform heat with actual combustor

Table 1

PUBLICATIONS

Reader, G.T., Potter, I.J., Clavelle, E. and Fauvel, O.R., 1998: "Low Power Stirling Engine for Underwater Vehicle Applications", *The IEEE Journal of Ocean Engineering*.

Reader, G.T., Potter, I.J., Clavelle, E. and Fauvel, O.R., 1998: "Low Power Stirling Engine for Underwater Vehicle Applications", Proceedings of the 1998 International Symposium on Underwater Technology, IEEE 98EX101, pp.411-416, Tokyo, Japan, April.

Potter, I.J., Reader, G.T., Clavelle, E., Bowen, C.E. and Gorin, S., 1997: "Combustion System Design for a Stirling Powered Diver Propulsion Vehicle", Proceeding ASME International Mechanical Engineering Congress, Paper OE-5B (4), Dallas, TX, November.

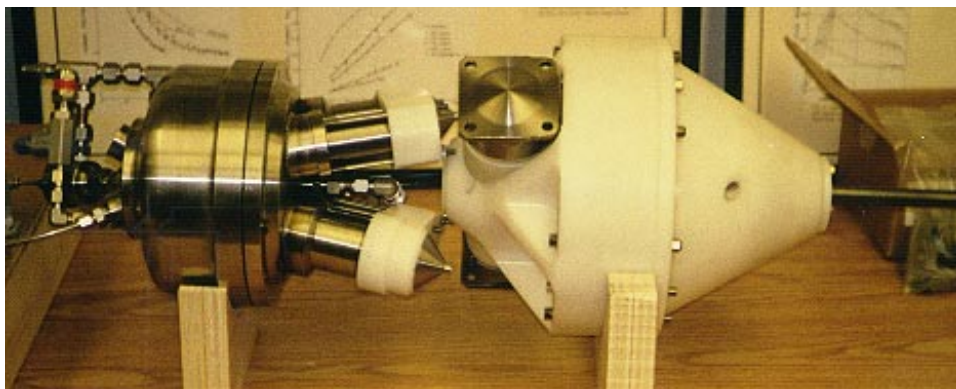


Figure 1

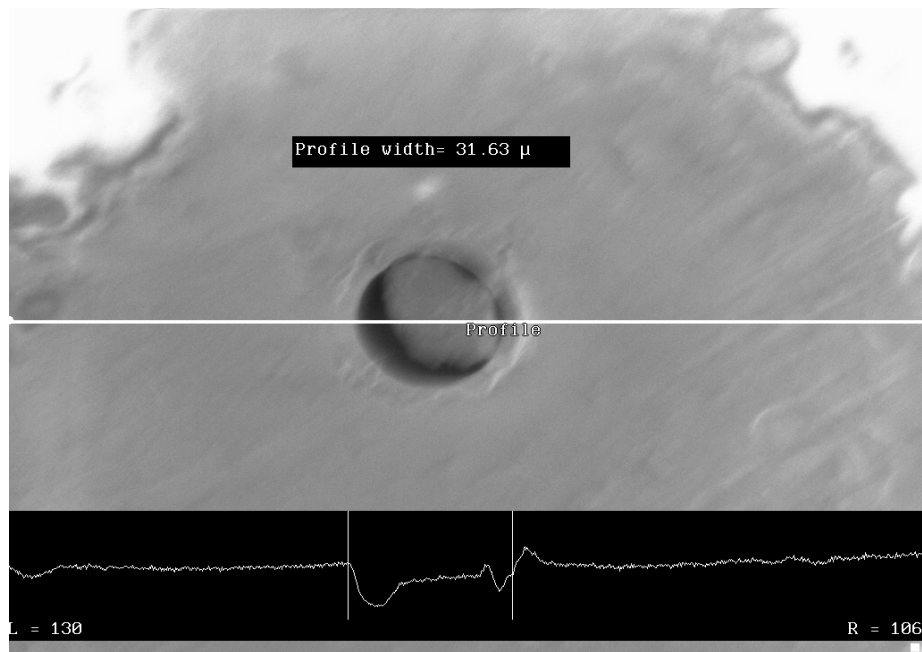


Figure 2